A POWER DISTRIBUTION/GENERATION SYSTEM

FIELD OF THE INVENTION

The present invention relates to a power distribution/generation system for supplying electrical power to a number of sites.

BACKGROUND OF THE INVENTION

Currently the electricity system in many countries relies on large power stations feeding a national transmission network, and thereby providing electricity for homes, commercial properties, industrial premises, and any other consumers. This arrangement means that power is often transmitted across significant distances, with resulting losses in the system. There are also considerable maintenance costs involved in such large transmission network, and a single failure can cause a great deal of inconvenience to a large number of consumers. In addition, the building of new power stations is often opposed due to environmental concerns, especially locally, where the power generated is not necessarily to be consumed close to its source. Distributed generators are currently in use by large consumers of electricity, and some of these are chp (combined heat and power) units. The heat produced during the generation of electricity in these generators can then be used locally for heating (water/space/industrial processes). This heat is a waste product when it is produced at a large power station as there is no local use for it, and the efficiency of the generation is therefore significantly lower than for the distributed generators.

Currently each distributed chp unit operates independently, matching the electricity and heat loads and importing/dumping energy as required to achieve

this. Imported power will generally be higher cost than that generated on site, and the dumping of power represents waste, resulting in increased energy costs.

WO-A-01/71881 shows a system for managing power where a distributed generator is present at a consumer site.

A controller determines an optimal source of power for the consumer site based on various criteria, and either causes power to be supplied from a grid network or from the distributed generator, depending for example on the relative cost of each at a given time. The system suffers nevertheless from a number of drawbacks. For example, if the total power requirement at the consumer site exceeds the total power available to be supplied by the distributed generator, power from the grid must then be drawn to supplement it. If the controller decides that it is cheaper to generate power locally, any excess power generated locally is wasted.

According to a first aspect of the present invention there is provided a power distribution/generation system for supplying electrical power to a number of sites, at least some of the sites comprising a generator, at least some of which are Stirling engines capable of generating electrical power, the generators being linked together on a local network, the local network being connectable to an external power grid, and a controller to control the distribution of power so that a site is supplied with electrical power from the local network if its demand exceeds the power generated by its generators, and so that power is drawn from the grid if the total power demand of all of the sites exceeds the power generated by all of the

generators.

In the local network, it is likely that one member will need to import electricity, while another has spare electrical capacity. By combining multiple sites in this way, it is possible to match the overall demand more closely and hence waste less energy or import less high-cost electricity from the grid giving increased environmental and economic benefits.

By incorporating an optional power storage unit on the network, e.g. a battery, mechanical storage such as a flywheel, pumped storage or superconducting magnetic storage, the power consumption of the network can be matched even more closely with the level of supply. This would minimize the requirement to import power and would thus minimize costs. Where a single generator, or a small number of units are involved, the economic benefits of such storage are outweighed by the cost of installation and maintenance. For larger networks, storage will present great benefits in reducing any power import from the grid, and will allow the network to stand alone without the need to place consumption limits on its members.

The applicant's current proposal is to use a Stirling engine as the combined heat and power unit. More particularly, our preference is for a linear free piston Stirling engine as this is able to operate as a combined heat and power unit quietly, efficiently and with acceptably low maintenance costs. In addition this is a synchronous machine where the speed of reciprocation, and therefore the frequency of the power generated, is constant.

A network of such generators would have the

advantage that each Stirling engine generator would automatically match the output frequency of the power it generates to that of the network. No external synchronising circuitry is then required to maintain a smooth waveform across the network. This would give superior power quality when compared with a network that uses predominantly an alternative design of generator, and minimise the potential for abnormal operation in installed domestic equipment incorporating waveform-sensitive timing circuitry.

The controller is preferably arranged to export excess power to the grid if the power generated exceeds the power demand of the local network. Thus, if it is economically favourable, the generators may be run to produce excess power for export. In the case of a combined heat and power unit this will generally be run to supply some, if not all, of the heat requirement for a site. Thus, at times of high heat demand and low power demand on the local network, excess power will be available for export, giving a potential economic benefit to network members. Where export is not an option, a power storage unit would allow this excess power to be stored for use at a later time.

If the economic conditions favour it, it may be preferable for the controller to be arranged to operate the combined heat and power unit to produce a power output to match, as far as possible, the power requirement of the local network. In other words, under these conditions, as much of the electrical power requirement as possible is supplied from the generators of the local network, rather than from the external grid. Depending upon the demand in the various sites, this may result in certain combined heat and power units being required to dump heat.

The connection between the local network and the grid may be implemented by each generator being individually linked to the grid. The requirements of the local network would, of course, also require the generators to be linked together to allow the distribution of power within the local network. However, preferably, all of the generators in the local network are routed through a hub which is then connected to the grid, as this avoids duplication of essential equipment required to connect to the grid.

Domestic heating systems conventionally require a supply of electrical power to power their control and ignition systems in order to operate. Therefore, during a power cut, not only do dwellings lose their electrical power supply, but they also lose their heating system. The system of the present invention is therefore preferably provided with means to detect the absence of mains power, wherein the controller is arranged to operate in the absence of mains power to supply electrical power to selected electricity consuming apparatus. As a priority, this electrical power should be supplied to the essential systems required to operate the combined heat and power systems to guarantee the consumer's heating system in the event of a power cut. This grid independent operation is the subject of our co-pending application no. 0130530.9

Under these grid independent conditions, the system can be arranged either to supply power to a dedicated emergency circuit in which case the power demand can be suitably limited. Alternatively, power may be selectively supplied to certain designated emergency sockets within a site. Under these circumstances, the power demand from the local network is in the hands of the consumer. If excess power is

demanded, this could damage the combined heat and power unit. Such damage may be prevented by a simple protection device (e.g. a fuse) to isolate the generators if excess power is demanded. However, preferably, the system comprises means to detect excess power demand, and to trim the peak voltage supplied to the selected sockets for a predetermined period of time. This voltage is trimmed to a level at which it will not damage sensitive equipment. However, it should be sufficient to provide a noticeable deterioration in the performance of the equipment, thereby alerting the consumer to the excess power demand and providing them with the opportunity to reduce this power demand. If the power demand is exceeded for longer than the predetermined period or if the power demand is increased further, the system is preferably provided with means to isolate the generators. Thus, if users fail to heed the excess power warning, ultimately the power to the selected components will be cut. However, the system can be arranged to restart following such a power cut once the demanded power load has been reduced.

Where a power store is present, this can provide power under grid independent conditions, so that the whole local network can continue to operate without the imposition of consumption limits on the members, using stored power to match peak consumption and recharging from the local generators at times of low overall consumption. Consumption limits will only be necessary in the unlikely event that a loss of mains power from the grid is experienced for an extended period of time such that the store is exhausted.

In order for the generators in the local network to communicate with the controller, some form of communication is required from each generator to the

controller. This may be done along a dedicated control network. However, preferably, the cables which carry the power to and from each site are also used as a carrier for the communication signals between the sites. Such technology is known in the art, for example, from US 4,641,322.

The present invention also extends to a method for supplying electrical power to a number of sites using a system according to the first aspect of the present invention, the method comprising the steps of monitoring the power generated by each generator, monitoring the power demand at each site, and controlling the distribution of power so that a site is supplied with electrical power from the local network if its demand exceeds the power generated by its generator, and drawing power from the grid if the total power demand of all of the sites exceeds the power generated by all of the generators.

BRIEF DESCRIPTION OF THE DRAWINGS

An example of a system in accordance with the present invention will now be described with reference to the accompanying drawings, in which:

Fig. 1 is a schematic diagram of a Stirling engine system providing an individual combined heat and power unit for use in the system of the present invention;

Fig. 2 is a plot of power against time showing the power demand for a number of dwellings, and the average power demand of these dwellings as a function of time; and

Fig. 3 is a schematic view of an overall system according to the present invention.

DETAIL DESCRIPTION OF A PREFERRED EMBODIMENT

Stirling Engine

The system preferably comprises a number of domestic combined heat and power (dchp) units as shown in Fig. 1. Each unit is based around a Stirling engine 1. The engine is preferably a linear free piston Stirling engine the operation of which is well known in the art. For use in a dchp system, the electrical output of the engine should be a single phase output of less than or equal to 16A.

The Stirling engine 1 is driven by a heat input from engine burner 2. This burner is fuelled by combustible fuel supply 3 which is mixed with an air supply 4 fed from a splitter valve 13 under the control of a valve 5. The fuel may be a combustible gas such as natural gas, LPG LNG or biogas. Alternatively, liquid fuel may be used. These fuels can also be used if the generator is something other than a Stirling engine. The mixed stream is fed to the burner 2 by a fan 6. This drives the Stirling engine in a manner well known in the art to generate an electrical output 7 from a linear alternator. Heat is extracted from the Stirling engine at cooler 8 which is essentially a heat exchanger through which water is pumped by a pump 9 along line 10. The water passing through the cooler 8 is then further heated in a heat exchanger 11 by exhaust gas from the engine burner which has heated the head of the Stirling engine. In order to provide further heating of the water, and to provide a degree of independence to heat the water when the Stirling engine is not being operated, a supplementary burner 12 is provided to heat the water in the heat exchanger 11. The supplementary burner is fuelled by a combustible gas

supply 3 which is mixed with an air supply 14, also fed from the splitter valve 13 under the control of a valve 15. The mixed stream is fed to the supplementary burner 12 by the fan 6.

Exhaust gases from the engine burner 2 and supplementary burner 12 which have given up their heat in the heat exchanger 11 then exit along flue 17. In this manner, the Stirling engine 1 produces an electrical output 7 and a heat output 18 which may be used, for example, to provide the domestic hot water requirement, or to feed a central heating system.

Introduction to Overall System

The local network of the present invention provides a way of connecting together multiple generators such as the dchp unit described above, along with other domestic power consumers and distributed generators. This allows the local network to smooth the overall supply and demand profiles illustrated in Fig. 2. Here the power demand profiles within three separate dwellings (House A, House B and House C) are combined to give a smoother overall curve which is labelled "Average Demand". The network can therefore use the combined power requirements and the total network generating capacity to balance out the needs between the network members. Where power storage is available (see below) the overall curve can be further smoothed to give an even greater saving, by reducing imported power still further.

An example of a system in accordance with the present invention will now be described with reference to Fig. 3.

In broad terms, Fig. 3 is divided by line 30 into

the grid 31 and its associated control circuitry shown above line 30, and the local network shown below the line 30. The local network consists of a number of sites, three types of which are shown schematically in Fig. 3. There may be any number of each of these types of dwelling in a particular local network. The first type of site 32 has a combined heat and power system and is configured both to have the capability to both import and export external power. The second type of site 33 is a consumer only unit with no generating capability and, as such, is typical of a present day dwelling. The third type of site 34 is a supplier only which exports power, but has no import requirement.

Grid System

The grid 31 and its associated circuitry will now be described. The hub interface is controlled under the action of hub controller 35. In fact, this controller 35 is responsible for regulating the distribution of power within the local network 35 and, as such, is as much a part of the local network as a part of the grid control system. Mains power from the grid 31 is connected into the controller via a system of protective devices including a main fuse 36 which provides ultimate protection for the local network. This will be of a rating suitable for the local distribution network. A hub meter 37 measures the import and export of power between the local network and the grid, allowing payment to be made as appropriate. Further grid protection is provided by hub grid protection control 38, hub grid isolation 39 and hub voltage controller 40. The hub grid protection control 38 monitors the voltage and frequency of the mains supply from the grid. This is described in greater detail in our earlier application

published as WO-A-02/061911. The hub grid isolation module 39 receives a "mains healthy/mains not healthy" signal from the hub grid protection control 38. It then acts either to maintain the mains link, or to isolate the local network, via a relay, if the mains supply is assessed to be of poor quality or to be absent. The hub voltage controller 40 comes into operation when the local network is isolated from the grid, when the hub controller 39 can no longer use the grid as a power sink for excess generating capacity. The hub voltage controller 40 is linked to the hub controller, so that excess power can be controlled. This maintains the voltage within the local network within preset limits. In addition a power storage unit 100 can be used to allow generation at times of low power demand, providing a benefit to combined heat and power systems on the network.

Sites of Local Network

The first type of site 32 has a dchp unit having an alternator, Stirling engine burner 2, supplementary burner 3 and heat exchanger 11 as shown in Fig. 1 to produce a heat output 18 to satisfy a domestic heat load 41, and an electrical power output 7. This is passed through a start/synchronous stop unit 42 via a fuse/manual isolator unit 43 which isolates the dchp unit from the power consuming appliances to a consumer unit 44. This consumer unit 44 also receives power from the grid hub controller 35, a mains communication unit 45 which monitors the state of the grid, via a conventional fuse 46 and a meter 47. From the consumer unit 44, the domestic loads 48 are supplied. This whole system is operated by a dchp unit controller 49 as described below.

The second type of site 33 is a consumer only

site having a conventional fuse 50 and meter 51 and a consumer unit 52 from which a number of domestic loads (not shown) are supplied.

The third type of site 34 is a supplier only. This comprises a generator 53 which may supply power to local loads, and which can export power via a manual isolator 54, meter 55, fuse 56 and mains communication unit 57 under the operational controller 58.

System Operation

The operation of the system will now be described.

The hub controller 35 monitors the voltage and current of the local network and signals the individual members to adjust their power outputs so as to maintain the local network voltage within preset limits (230V ± 10%). For example, if the operator is a Stirling engine as described, this is achieved by continuous transmittal of signals from the units informing the hub of the Stirling engine burner 2 setting (-1:0ff, 0: modulating +1: full) at any time. The hub controller 35 will return a + 1, 0 or -1 signal to indicate that the burner output should be increased, stay the same, or reduced by a preset increment. In this way the individual dchp unit power outputs are adjusted to suit the network demand at any time.

If a -1 signal continues to be sent to the hub controller 35, despite continued requests for an increase in burner output, the hub will interpret this as a burner fault. A service visit to this dchp unit will then be initiated automatically. This will not

cause any inconvenience to the consumer concerned, as the remaining network capacity will continue to feed this dwelling until the fault can be rectified.

If a +1 signal continues to be sent to the hub controller 35, despite continued requests for a decrease in burner output, the hub will interpret this as a local heat demand in excess of that which would be produced at the requested burner setting. In this case, the hub controller 35 will allow the dchp unit 1 to maintain excess generating output. As long as the dwelling is connected to the network this power will flow onto the network, and the hub controller 35 will operate to allow another consumer to make use of it, export it to the grid, dissipate it via the hub voltage controller 40, or store it in the power storage unit 100 if present.

If the local heat demand is insufficient to dispose of all of the heat produced at the requested burner setting, the dchp unit 1 will initiate heat disposal using the fan 16 for the inactive supplementary burner 12 to blow cool air into the heat exchanger 11.

Power Maximisation (Voltage reduction)

Where the power demanded by the local network increases to exceed the maximum generating capacity of the network, the hub controller 35 will normally monitor the import of additional power from the Grid, via the hub meter 37. Where a power storage unit 100 is present this will provide a source of additional power for the hub controller to access in preference to the grid. If the mains connection is not present, the network is operating independently, and the power storage unit 100 where present, is fully discharged,

the available power will be maximised by using a voltage waveform reduction technique as the current increases within the network, to maintain the power output within the generating capability of the local network. The voltage can be reduced by 10-15%, depending on the type of equipment involved, with minimal effects. The visible effects of the voltage reduction act as a warning to the consumers that no additional equipment should be connected to the network until, either the power demand reduces naturally, or until mains power is available to import. The larger the network is, the less likely this is to occur, as the average consumption at any time is less likely to exceed the total generating capacity.

Grid Reconnection

Under mains failure conditions, once the mains link is disconnected, the hub grid isolation module 39 waits until the hub grid protection control 38 sends a mains healthy signal once more. As the network voltage will be unsynchronised with the mains after a period of independent operation, this reconnection may necessitate that the generators be shut down and restarted once the grid supply has been reconnected. To minimise inconvenience to the users, this would be undertaken once the power demand is minimal. The hub controller 35 would determine the best time for this, waiting until the demand drops below a preset level, generally during the night. Alternatively, resynchronisation of the operating generators may be carried out without a shutdown and restart. This can be achieved by monitoring the network and grid waveforms and appropriately controlling the reconnection as they coincide.

After a 3 minute period of healthy mains supply it can be reconnected to the local network. All generators connected to the local network will be shut down, and the grid supply will be reconnected at the hub grid isolation module 39. Power will therefore be restored to the sites almost instantaneously. The dchp units 1 will wait until the Stirling engine burners have cooled sufficiently to allow a restart. Other generators will have similar safe restart periods, after which they can resume generation. The hub controller 35 will then restore the balance across the network.

Communication between Sites

In order for the systems of each site 32-34 to be combined, some form of communication is needed between them. The mains cables used to transmit the power across the local network can also be used as a carrier for the communication signals. Such technology is known and easily adapted for this purpose.

Each exporting site 32,34 has a mains communication unit 45,57 connected at the network link. This receives signals from the controllers 49,58 for the individual generators, and sends and receives all trimming signals to and from the hub controller 35.

Where the site 32 has a dchp unit 1, the mains communication unit 45 receives signals from the dchp unit controller 49 relating to the Stirling engine burner setting (-1:off, 0: modulating, +1: full) at any time. This is converted to the appropriate signal and transmitted to the hub controller 35 via the mains cables. The hub will return a +1, 0 or -1 signal to indicate that the burner output should be increased,

stay the same, or reduced by a preset increment. The mains communication unit interprets this signal and informed the dchp unit controller so that, heat demand permitting, the Stirling engine burner can be adjusted accordingly. In this way the individual dchp unit power outputs are adjusted to suit the network demand at any time.

Similarly, where the site 35 has a distributed generator 53 the mains communication unit 57 receives a signal from the hub controller specifying whether the power generated should be increased (+1), stay the same (0), or reduced (-1). This will be conveyed to the controller 58 operating the distributed generator, which will return a signal indicating the current status of the generator (-1: off, 0: modulating, +1: full) at any time. This is converted to the appropriate signal and transmitted to the hub controller 35 via the mains cables.

Where a site 33 is a consumer only, there is no generator to adjust, so no trimming signals are sent across the network. The consumer link does not therefore need a mains communication unit, reducing the installation costs, and allowing the connection to be equivalent to the existing mains connection arrangement.

Network Control Strategy (Power led, including Power Storage Unit

The hub controller 35 will always transfer power to and from the storage facility in preference to exporting to and importing from the grid. Only where the power store is fully charged or fully discharged will the grid be accessed. The size of the power store and the size of the network will determine the level

of power transfer between the grid and the local network, but it will be minimized at all times to achieve the maximum economic benefit.

Network Control Strategy (Power led, no Power Storage Unit)

The hub controller 35 will always act to minimise excess power for which there is no economic demand (local use or chargeable export).

- Where power can be exported to the grid 31, the hub controller 35 will trim the network generating capacity to maximise this. Any communication with the central grid control system will take place with the hub controller 35, so that the arrangement can be operated to be beneficial to all concerned. The presence of this hub controller 35 makes the co-operative network into the equivalent of a larger distributed generating plant as far as the grid is concerned.

- Where no benefit will be derived from export, but it is allowed, the hub controller 35 will use the grid 31 as a pure power sink, only using export to maintain the network voltage within the preset limits.

- Where export to the Grid is not allowed the hub controller 35 will import power as required to satisfy excess demand within the network, but will dissipate excess power using the hub voltage controller 40.

- Under grid independence excess power will be dissipated through the hub voltage controller 40,

but no import will be possible. The hub controller 35 will then be responsible for maintaining the voltage level within the network by trimming the generators as appropriate.

The control strategy used by the hub controller is therefore based on the power demand within the local network, whereas the control strategy within each site 32 is heat led. The individual units send regular signals to the hub informing of the power output generated at any time (via the Stirling engine burner setting signal or a power meter in the control system). The hub controller 35 then acts to either increase the power fed onto the local network by increasing the individual generator outputs, reduce it by decreasing the individual generator outputs, or maintain the status quo. The individual generators are responsible for dissipating any excess heat produced while generating at the required level, but can feed any excess power, generated in the process of satisfying the local heat demand, onto the network where the hub controller 35 will dispose of it.

It is advantageous to keep as many units as possible generating at any time, so that when a sudden increase in power demand occurs, this can be quickly satisfied by first increasing the power output from the active units. Other units can then be switched on and the load balanced between them over the course of a few minutes. The overall system then becomes more responsive to consumer demand than it is possible for a single unit to be. The power storage unit 100, where present, will also increase the response of the network to changes in demand, allowing an increase in power demand to be satisfied immediately while the network overall generating capacity is increased to match this over the space of a few minutes.

Even with a network consisting of the minimum two dchp units, at least one unit will be generating at any time, so that there is sufficient power available for the pumps, control circuitry, etc. (currently around 200W per unit). With larger networks, it is possible to run a number of units at the minimum setting, allowing the power output to be increased quickly when required. The minimum generating output of a dchp unit reflects the power generated when the engine burner is at its lowest setting (currently 4 kW calorific input to burner), and is around 0.4 kWe.

Fault Currents

The fault, or short circuit current for the Stirling engine generator described previously is similar to that from domestic appliances of an equivalent rating (e.g. a 1kW vacuum cleaner), due to the low inertia of the Stirling engine. Suitable protection equipment installed in addition to the fuses 36, 46, 50, 56, provides the required protection should a fault occur.